NIST National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Developing Standard Performance Tests for Response Robots

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National Institute of Standards and Technology

NIST strengthens the U.S. economy and improves the quality of life by working with industry to develop and apply technology, measurements, and standards

NIST carries out its mission through a portfolio of four programs:

Measurements and Standards

Technology Innovation

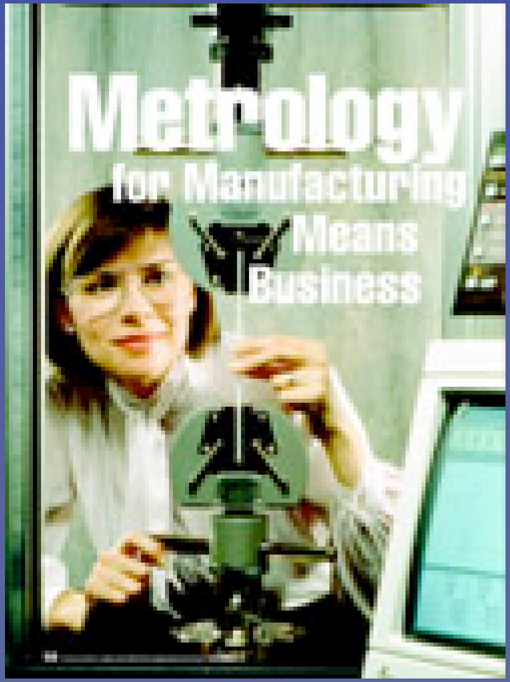
Manufacturing Extension Partnership

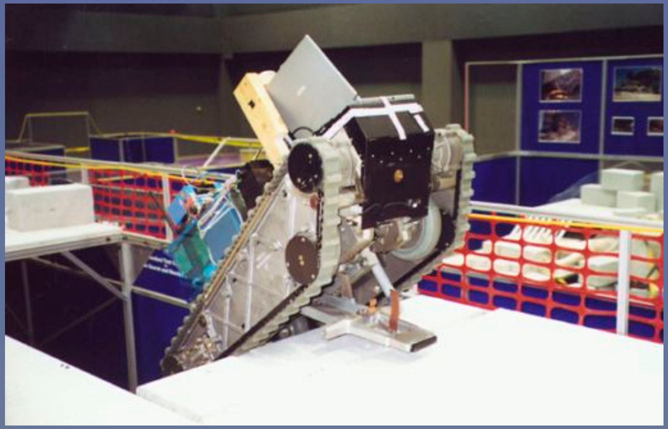
Baldrige National Quality

Intelligent Systems Division Mission

To develop the measurements and standards infrastructure needed for the application of intelligent systems

- Manufacturing applications
- Robotic and operator-assist systems for defense, public safety and security, transportation, …





Why do we think unmanned systems are important?

- Demonstrated value and dramatic potential to save lives, improve performance and safety, provide new capabilities, and reduce operational costs
- Will fundamentally change how our national defense forces operate
- Poised to be the most dynamic growth area in aerospace, automotive, and other industries

Unmanned systems are important to our customers and stakeholders, who have come to us for help with key challenges

How do we help?

- We help our customers define, specify, measure, and evaluate unmanned system performance and capabilities
  - Requirements and performance standards
  - Repeatable, objective, quantitative test methods and associated environments, artifacts, and data
- We help our customers build next-generation unmanned systems
  - Intelligent systems engineering methodology, perception, knowledge representation, development and testing tools
  - Interface standards

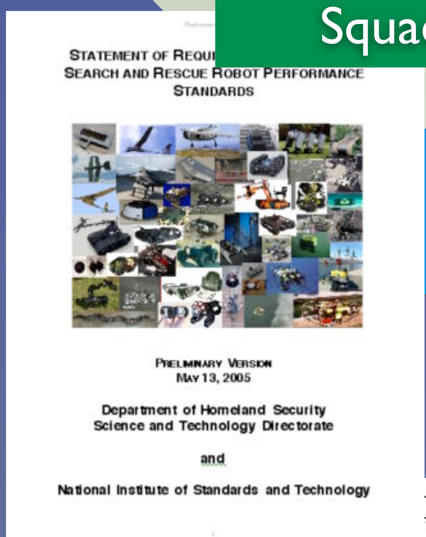
Performance Metrics and Standards for Homeland Security Robots

- NIST has been working with other agencies to develop performance requirements, metrics, and standard test methods for homeland security robots
  - Department of Homeland Security Performance Standards for Urban Search and Rescue Robots
  - National Institute of Justice Performance Standards for Bomb Disposal Robots
- Standard performance metrics and tests will enable agencies and users to obtain the *best value* for their investment in robots, to *save lives* through broader deployment of robots, and to help robot suppliers *accelerate development* of advanced capabilities.

Toward Performance Standards for Homeland Security Robots

Requirements from FEMA Teams & Bomb Squads → Standard Test Methods → "Consumer's Guide"

Responders Meet Robots Exercises

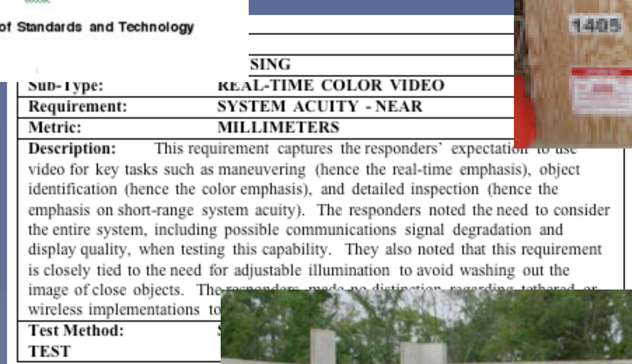

STATEMENT OF REQUI[...]
SEARCH AND RESCUE ROBOT PERFORMANCE STANDARDS

PRELIMINARY VERSION
MAY 13, 2005

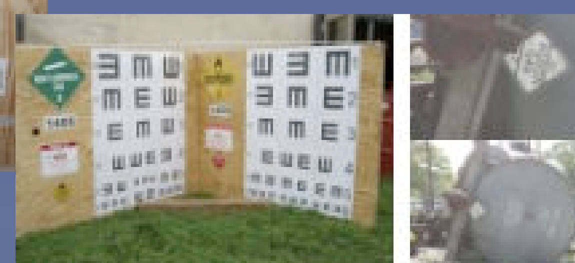
Department of Homeland Security
Science and Technology Directorate

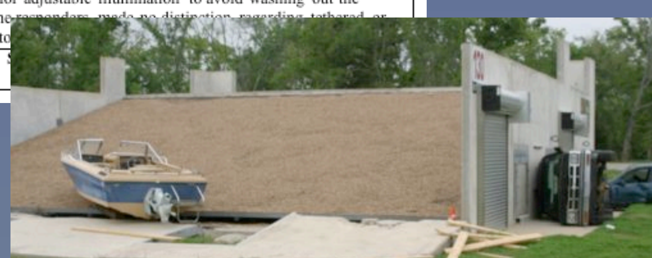
and

National Institute of Standards and Technology



	[...]SING
Sub-Type:	REAL-TIME COLOR VIDEO
Requirement:	SYSTEM ACUITY - NEAR
Metric:	MILLIMETERS
Description:	This requirement captures the responders' expectation to use video for key tasks such as maneuvering (hence the real-time emphasis), object identification (hence the color emphasis), and detailed inspection (hence the emphasis on short-range system acuity). The responders noted the need to consider the entire system, including possible communications signal degradation and display quality, when testing this capability. They also noted that this requirement is closely tied to the need for adjustable illumination to avoid washing out the image of close objects. The[...] wireless implementations to[...]
Test Method:	
TEST	





Homeland Security

DHS Performance Metrics and Standards for US&R Robots Program Goals

- Develop STANDARD TEST METHODS for performance and use of USAR robots based on explicitly captured requirements:
  - ✳ System capabilities: Mobility, Communications, Sensors, Power, . . .
  - ✳ Operating environments
  - ✳ Logistics
  - ✳ Human-system interaction
- Work within Consensus Standards Process: **ASTM E54.08**
- Leverage work of SAE AS-4, IEEE, other ASTM standards, others
- Enable the Department of Homeland Security to provide guidance to local/state/federal homeland security entities regarding purchase, deployment, and use of these emerging tools

What Must USAR Robots Do?

(mobility, power, sensors, communications, operator interfaces, ...)

What are the requirements?
How can we quantify robot performance in specific areas?
How can we abstract domain challenges?
How can we make them *reproducible, repeatable*?

What Does a Mobile Robot Need to Do? Example Application: Urban Search and Rescue (US&R)

US&R refers to rescue activities in collapsed buildings and structures

- <u>Application Goals</u>
  - Explore a structure, map significant features
  - Locate victims
  - Deliver emergency kits (radio, water, first aid…)
  - Transmit a human readable map
- Hazardous task
  - Lives saved by removing human rescuers
  - Compromised structures, limited access areas
  - Robots are ultimately expendable
- Time critical
  - Great benefit from quickly locating victims
  - Requires careful path planning and strategy
- Highly unstructured/unpredictable
  - Requires adaptability, decision-making
  - Negotiation = Navigation + Influence

Responder Requirements

Requirements Category	Number of Individual Requirements	Category Definition
Human-System Interaction	23	Pertaining to the human interaction and operator(s) control of the robot
Logistics	10	Related to the overall deployment procedures and constraints in place for disaster response
Operating Environment	6	Surroundings and conditions in which the operator and robot will have to operate
System		The main body of the robot, upon which additional components and capabilities may be added. This is the minimum set of capabilities (base platform)
Chassis	4	The main body of the robot, upon which additional components and capabilities may be added.
Communications	5	Pertaining to the support for transmission of information to and from the robot, including commands for motion or control of payload, sensors, or other components, as well as underlying support for transmission of sensor and other data streams back to operator
Mobility	12	The ability of the robot to negotiate and move around the environment
Payload	7	Any additional hardware that the robot carries and may either deploy or utilize in the course of the mission
Power	5	Energy source(s) for the chassis and all other components on board the robot
Sensing	32	Hardware and supporting software which sense the environment
Safety	1	Pertaining to safety of humans and potentially property in the vicinity of robots

Example Responder-Defined Requirements

Sensing	Real-time Video	Resolution of the image will be tested using visual acuity tests at given range. Image should be in color. Quality is evaluated through entire system (i. e., not standalone).
Logistics	Field Maintenance: Tools	Scale Defined: 1= Requires Special Tools; 3=Simple Tools (e.g., screw driver); 5=No Tools Required
Power (Energy)	Working Time	System working time beyond mobility requirements. Assumes one power charge; one out and back mission. Scale defined: 1=1hr; 3=4hrs; 5=12hrs.

Robot Deployment Categories

Ground: Peek Robots
Ground: Collapsed Structure--Stair/Floor climbing, map, spray, breach Robots
Ground: Non-collapsed Structure--Wide area Survey Robot
Ground: Wall Climbing Deliver Robots
Ground: Confined Space, Temporary Shore Robots
Ground: Confined Space Shape Shifters
Ground: Confined Space Retrieval Robots
Aerial:High Altitude Loiter Robots
Aerial: Rooftop Payload Drop Robots
Aerial: Ledge Access Robot
Aquatic: Variable Depth Sub Robot
Aquatic: Bottom Crawler Robot
Aquatic: Swift Water Surface Swimmer

Example Deployment Categories for Robots

Robot Category	Ground: Peek Robots
Employment Roles(s)	Provide rapid audio visual situational awareness; provide rapid HAZMAT detection; data logging for subsequent team work
Deployment Method(s)	Tossed, chucked, thrown pneumatically, w/ surgical tubing; marsupially deployed
Tradeoffs	Trade mobility, duration, sensing for increased expendability

Omnitech Toughbot

Some commercial products are shown for illustration purposes. This does not imply endorsement by NIST.

Example Deployment Categories for Robots

Robot Category	Ground: Non-Collapsed Structure –Wide Area Survey
Employment Roles(s)	Long range, human access stairway & upper floor situational awareness; contaminated area survey; site assessment; victim identification; mitigation activities; stay behind monitoring
Deployment Method(s)	Backpacked; self driven; marsupially deployed
Tradeoffs	Experience form factor for increased mobility, sensing, manipulation; mapping variant; spraying variant; breaching variant

iRobot Packbot

Example Deployment Categories for Robots

Robot Category	Aerial –Wide Area Survey (& Loiter)
Employment Roles(s)	Provide overhead perspective & sit. Awareness; provide HAZMAT plume detection; provide comm repeater coverage
Deployment Method(s)	Released; balloon or F/W; tethered; launched; VTOL
Tradeoffs	Trade penetration capacity for vertical perspective (in some cases); trade simplicity for greater sit. Awareness.

ASTM E54.08.01 Working Groups

Homeland Security Applications, Operational Equipment, US&R Robot Performance Standards

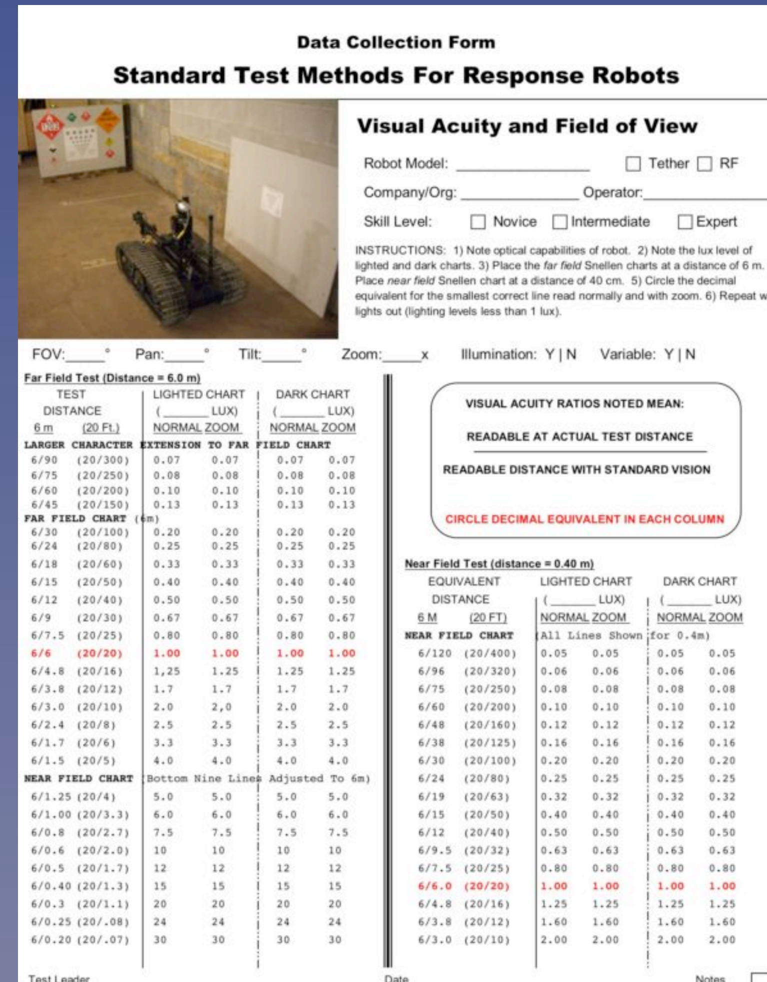
- Terminology
- Logistics
- Safety and Operating Environment
- Communications
- Human-System Interaction
- Sensing
- Mobility
- Power (renamed Energy)

ASTM E54.08.01 Working Groups

- 6 Work Items introduced; 3 balloted
  - ✳ Visual Acuity and Field of View (E2566)
  - ✳ Terminology (E2521-07a)
  - ✳ Logistics, Cache Packaging (E2592-07)
  - ✳ Communications: Line of sight and Non-line of sight wireless
  - ✳ Human-System Interaction: Usability
  - ✳ Mobility
- Additional ones in queue
  - ✳ Safety
  - ✳ Power

Example: Visual Acuity & FOV Test Method

Requirements	
Illumination	Adjustable
Video	Real-time remote video system (near)
Video	Real-time remote video system (far)
Video	Field of View
Video	Pan
Video	Tilt



Data Collection Form

Standard Test Methods For Response Robots

Visual Acuity and Field of View

Robot Model: ____________ ☐ Tether ☐ RF

Company/Org: ____________ Operator: ____________

Skill Level: ☐ Novice ☐ Intermediate ☐ Expert

INSTRUCTIONS: 1) Note optical capabilities of robot. 2) Note the lux level of lighted and dark charts. 3) Place the *far field* Snellen charts at a distance of 6 m. 4) Place *near field* Snellen chart at a distance of 40 cm. 5) Circle the decimal equivalent for the smallest correct line read normally and with zoom. 6) Repeat with lights out (lighting levels less than 1 lux).

FOV:_____° Pan:_____° Tilt:_____° Zoom:_____x Illumination: Y | N Variable: Y | N

Far Field Test (Distance = 6.0 m)

TEST DISTANCE		LIGHTED CHART (_______ LUX)		DARK CHART (_______ LUX)	
6 m	(20 Ft.)	NORMAL	ZOOM	NORMAL	ZOOM
LARGER CHARACTER EXTENSION TO FAR FIELD CHART					
6/90	(20/300)	0.07	0.07	0.07	0.07
6/75	(20/250)	0.08	0.08	0.08	0.08
6/60	(20/200)	0.10	0.10	0.10	0.10
6/45	(20/150)	0.13	0.13	0.13	0.13
FAR FIELD CHART (6m)					
6/30	(20/100)	0.20	0.20	0.20	0.20
6/24	(20/80)	0.25	0.25	0.25	0.25
6/18	(20/60)	0.33	0.33	0.33	0.33
6/15	(20/50)	0.40	0.40	0.40	0.40
6/12	(20/40)	0.50	0.50	0.50	0.50
6/9	(20/30)	0.67	0.67	0.67	0.67
6/7.5	(20/25)	0.80	0.80	0.80	0.80
6/6	(20/20)	1.00	1.00	1.00	1.00
6/4.8	(20/16)	1,25	1.25	1.25	1.25
6/3.8	(20/12)	1.7	1.7	1.7	1.7
6/3.0	(20/10)	2.0	2,0	2.0	2.0
6/2.4	(20/8)	2.5	2.5	2.5	2.5
6/1.7	(20/6)	3.3	3.3	3.3	3.3
6/1.5	(20/5)	4.0	4.0	4.0	4.0
NEAR FIELD CHART (Bottom Nine Lines Adjusted To 6m)					
6/1.25	(20/4)	5.0	5.0	5.0	5.0
6/1.00	(20/3.3)	6.0	6.0	6.0	6.0
6/0.8	(20/2.7)	7.5	7.5	7.5	7.5
6/0.6	(20/2.0)	10	10	10	10
6/0.5	(20/1.7)	12	12	12	12
6/0.40	(20/1.3)	15	15	15	15
6/0.3	(20/1.1)	20	20	20	20
6/0.25	(20/.08)	24	24	24	24
6/0.20	(20/.07)	30	30	30	30

VISUAL ACUITY RATIOS NOTED MEAN:

READABLE AT ACTUAL TEST DISTANCE / READABLE DISTANCE WITH STANDARD VISION

CIRCLE DECIMAL EQUIVALENT IN EACH COLUMN

Near Field Test (distance = 0.40 m)

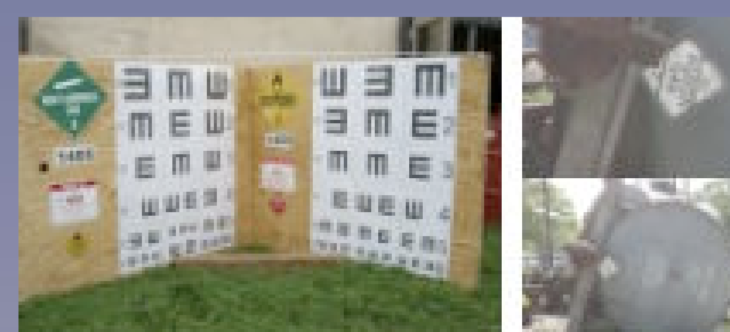
EQUIVALENT DISTANCE		LIGHTED CHART (_______ LUX)		DARK CHART (_______ LUX)	
6 M	(20 FT)	NORMAL	ZOOM	NORMAL	ZOOM
NEAR FIELD CHART (All Lines Shown for 0.4m)					
6/120	(20/400)	0.05	0.05	0.05	0.05
6/96	(20/320)	0.06	0.06	0.06	0.06
6/75	(20/250)	0.08	0.08	0.08	0.08
6/60	(20/200)	0.10	0.10	0.10	0.10
6/48	(20/160)	0.12	0.12	0.12	0.12
6/38	(20/125)	0.16	0.16	0.16	0.16
6/30	(20/100)	0.20	0.20	0.20	0.20
6/24	(20/80)	0.25	0.25	0.25	0.25
6/19	(20/63)	0.32	0.32	0.32	0.32
6/15	(20/50)	0.40	0.40	0.40	0.40
6/12	(20/40)	0.50	0.50	0.50	0.50
6/9.5	(20/32)	0.63	0.63	0.63	0.63
6/7.5	(20/25)	0.80	0.80	0.80	0.80
6/6.0	(20/20)	1.00	1.00	1.00	1.00
6/4.8	(20/16)	1.25	1.25	1.25	1.25
6/3.8	(20/12)	1.60	1.60	1.60	1.60
6/3.0	(20/10)	2.00	2.00	2.00	2.00

Test Leader

Date

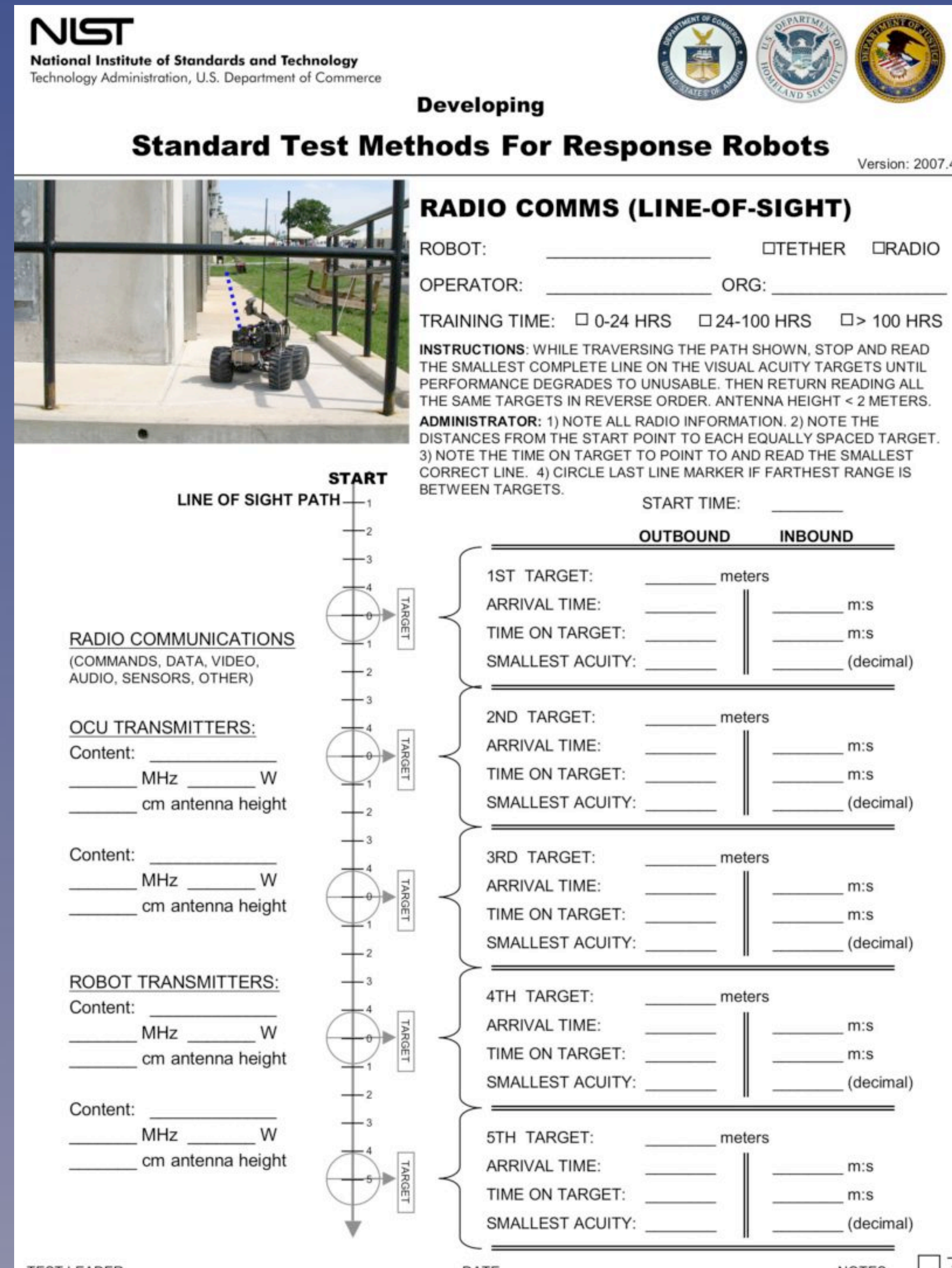
Notes

Snellen Eye chart correlated to Relevant Visual Targets



Example: Wireless Communications Range

Requirements Addressed	
Communications	Range - Line of Sight
Communications	Range - Beyond Line of Sight



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Developing
Standard Test Methods For Response Robots
Version: 2007.4

RADIO COMMS (LINE-OF-SIGHT)

ROBOT: ______ ☐TETHER ☐RADIO
OPERATOR: ______ ORG: ______
TRAINING TIME: ☐ 0-24 HRS ☐ 24-100 HRS ☐ > 100 HRS

INSTRUCTIONS: WHILE TRAVERSING THE PATH SHOWN, STOP AND READ THE SMALLEST COMPLETE LINE ON THE VISUAL ACUITY TARGETS UNTIL PERFORMANCE DEGRADES TO UNUSABLE. THEN RETURN READING ALL THE SAME TARGETS IN REVERSE ORDER. ANTENNA HEIGHT < 2 METERS.
ADMINISTRATOR: 1) NOTE ALL RADIO INFORMATION. 2) NOTE THE DISTANCES FROM THE START POINT TO EACH EQUALLY SPACED TARGET. 3) NOTE THE TIME ON TARGET TO POINT TO AND READ THE SMALLEST CORRECT LINE. 4) CIRCLE LAST LINE MARKER IF FARTHEST RANGE IS BETWEEN TARGETS.

START
LINE OF SIGHT PATH

START TIME: ______

RADIO COMMUNICATIONS
(COMMANDS, DATA, VIDEO, AUDIO, SENSORS, OTHER)

OCU TRANSMITTERS:
Content: ______
______ MHz ______ W
______ cm antenna height

Content: ______
______ MHz ______ W
______ cm antenna height

ROBOT TRANSMITTERS:
Content: ______
______ MHz ______ W
______ cm antenna height

Content: ______
______ MHz ______ W
______ cm antenna height

	OUTBOUND	INBOUND	
1ST TARGET:	______ meters		
ARRIVAL TIME:	______	______	m:s
TIME ON TARGET:	______	______	m:s
SMALLEST ACUITY:	______	______	(decimal)
2ND TARGET:	______ meters		
ARRIVAL TIME:	______	______	m:s
TIME ON TARGET:	______	______	m:s
SMALLEST ACUITY:	______	______	(decimal)
3RD TARGET:	______ meters		
ARRIVAL TIME:	______	______	m:s
TIME ON TARGET:	______	______	m:s
SMALLEST ACUITY:	______	______	(decimal)
4TH TARGET:	______ meters		
ARRIVAL TIME:	______	______	m:s
TIME ON TARGET:	______	______	m:s
SMALLEST ACUITY:	______	______	(decimal)
5TH TARGET:	______ meters		
ARRIVAL TIME:	______	______	m:s
TIME ON TARGET:	______	______	m:s
SMALLEST ACUITY:	______	______	(decimal)

TEST LEADER DATE NOTES

Example: Logistics - Cache Packaging

Packaging: Volume, Weight

Setup Time

Field Repair Tools

Downrange Weight

NIST
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Developing
Standard Test Methods For Response Robots

Logistics - Cache Packaging

ROBOT: ______________ ☐ TETHER ☐ RF

OPERATOR: ______________ ORG: ______________

SKILL LEVEL: ☐ Novice ☐ Intermediate ☐ Expert

INSTRUCTIONS: 1) Note the number and weight of each packaging container necessary for robot to deploy for 10 days, without re-supply for the first 72 hours. 2) Time the setup process until ready to go downrange. 3) Note the tools needed to perform setup and repair. 4) Weigh the deployable robot and operator control unit.

Planning for a 10 day deployment, without resupply for the first 72 hours

Number of packages:
_____ Pelicans _______ kg or ______ lb
_____ Hardiggs _______ kg or ______ lb
_____ Ropacks _______ kg or ______ lb
_____ Pallets _______ kg or ______ lb

Total Weight: _______ kg or ______ lb

Measure the length of time to unpackage the robot system and fully prepare it for deployment.

Setup Time:
Start Time: ____________
End Time: ____________
Elapsed: ____________ minutes

Setup and Reparis can be performed at the base of operation

Tools Needed:
☐ None
☐ Typical Toolbox: Metric or English (circle one)
☐ Any Specialized Tools: Describe: ______________________
Describe: ______________________
Describe: ______________________

Down-Range Weight:
Robot: __________ kg Operator Control Unit: __________ kg Total: __________ kg
Robot: __________ lbs Operator Control Unit: __________ lbs Total: __________ lbs

TEST LEADER DATE NOTES ☐

Example: Mobility - Step Test

Description:

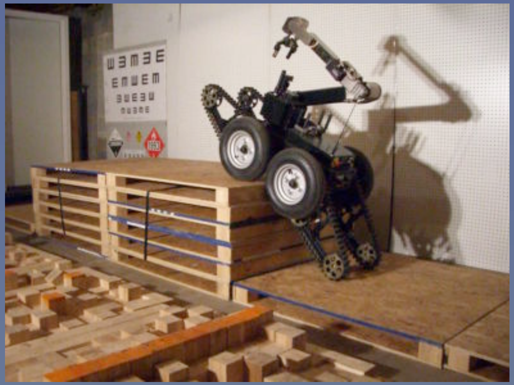
- 10 cm increments
- Low friction edges (rolling PVC pipe)
- Emphasizes shape shifting capabilities
- Repeat 10 times at highest achievable elevation

Requirements:

- Mobility: Locomotion: Sustained Speed - Obstacles (steps/min)
- Mobility: Tumble Recovery Within Terrain Type (none:self-righting:invertible continuous operations)

Additional:

Mobility: Locomotion: Negotiation: Ledge (maximum step height)

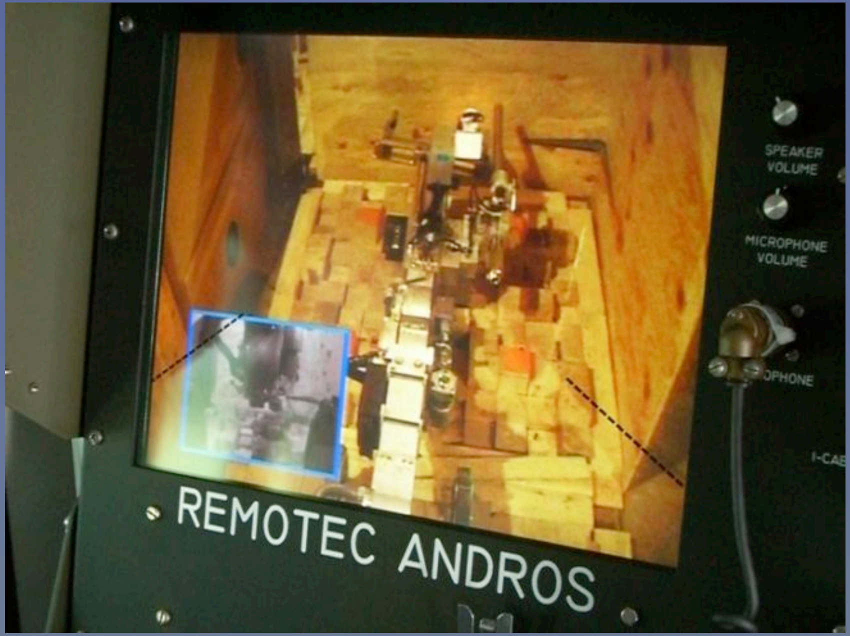


Bill McBride, Kevin Alley
Southwest Research Institute

Adam Jacoff, Tony Downs
Intelligent Systems Division, NIST

Example: Directed Perception Test Method

(eye charts, hazmat labels, thermal, chemical, radiological, explosive)




Cache Packaging

Confined Space




Human Factors

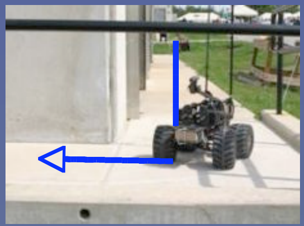
Stairs




Visual Acuity

Mobility/Endurance

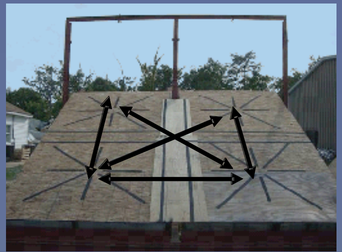
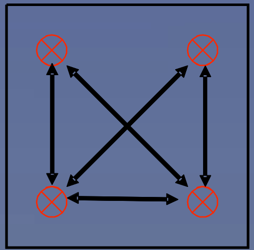


Radio Comms

HRI Usability



Inclined Plane

Directed Perception

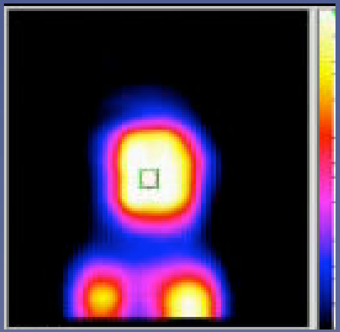



Random Stepfields

Grasping Dexterity


Common Underlying Artifacts & Measurement Infrastructure

Random Step Fields (Red, Orange)



Targets (Eye Charts, HazMat Labels, Thermal Emitters)

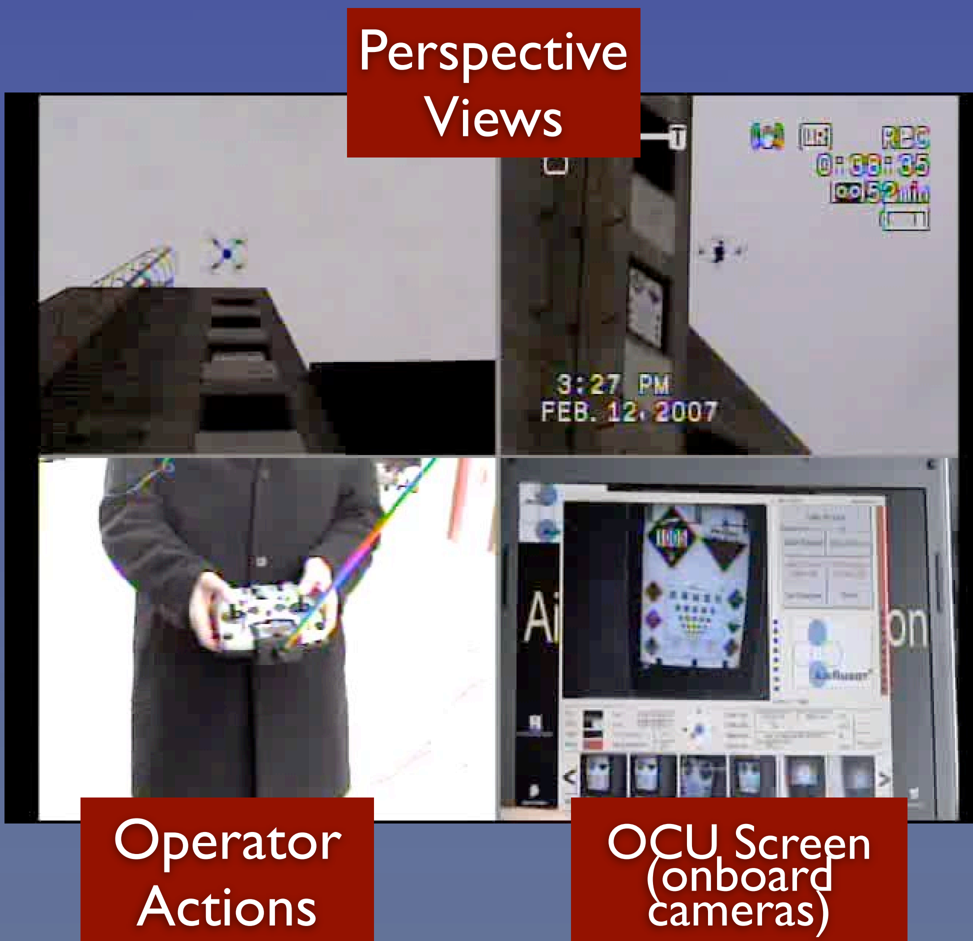
Pitch/Roll Ramps (Rolling Terrain)

Repeatable Terrain

Grasping Props (Wood Blocks, simulated Pipe Bombs, Mineral Water Bottles, etc.)

Inexpensive, but how exhaustive & representative do we have to be?

Collecting Performance Data

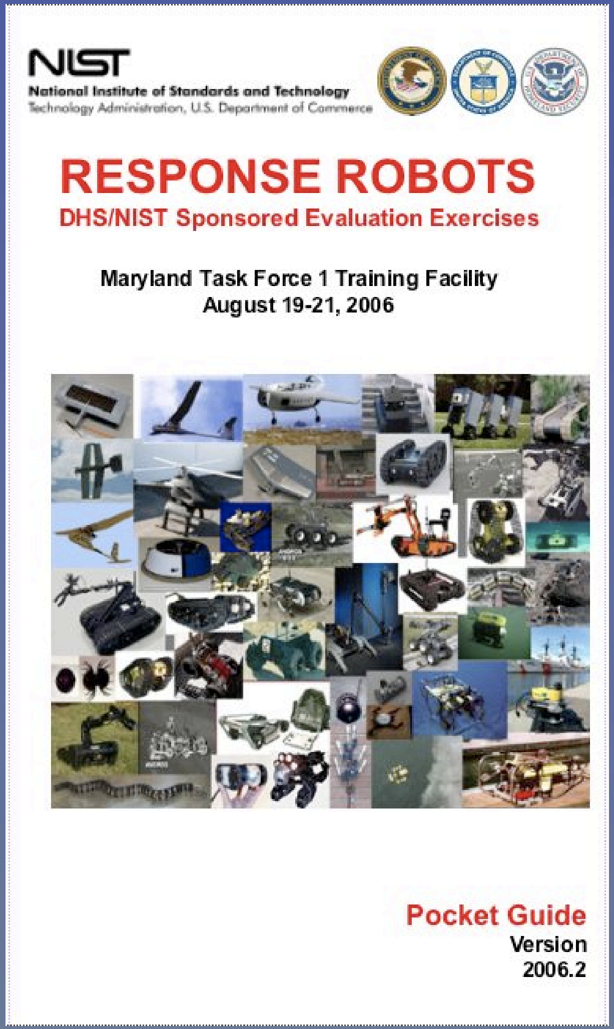


Aerial Stationkeeping & Visual Acuity Test Method

Human-System Interaction: Usability Test Method

Pocket Guide - Per Event

http://www.isd.mel.nist.gov/US&R_Robot_Standards/



- Program Overview
- Event Introduction
- Site Overview
- Safety
- Test Methods and Artifacts
- Participating Robots
  - Ground
  - Wall Climbers
  - Aerial
  - Aquatic
- Sensors
- Index

Response Robot Exercises: Validating the Tests; Characterizing the Application

- Held at FEMA US&R Training Facilities
  - *Nevada (8/05)*
  - *Texas (4/06, 6/07)*
  - *Maryland (8/06)*
- 23 FEMA Task Forces have Participated
- 34 organizations have brought 46 robots (aerial, ground, aquatic)

Homeland Security

NIST

Response Robot Evaluation Exercise

TX-TF1 Training Facility - Disaster City
College Station, TX
April 4-6, 2006
(with a standards meeting April 7, 2006)
www.isd.mel.nist.gov/us&r_robot_standards
usar.robots@nist.gov

TEXAS A&M SYSTEM

TEEX TRAIN • SERVE • RESPOND

Jouster

Homeland Security

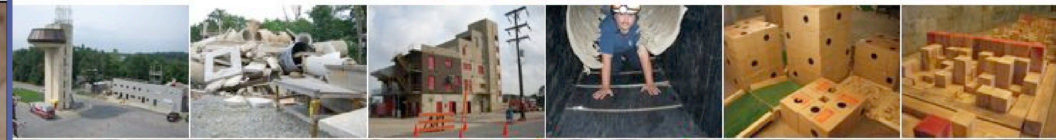
NIST

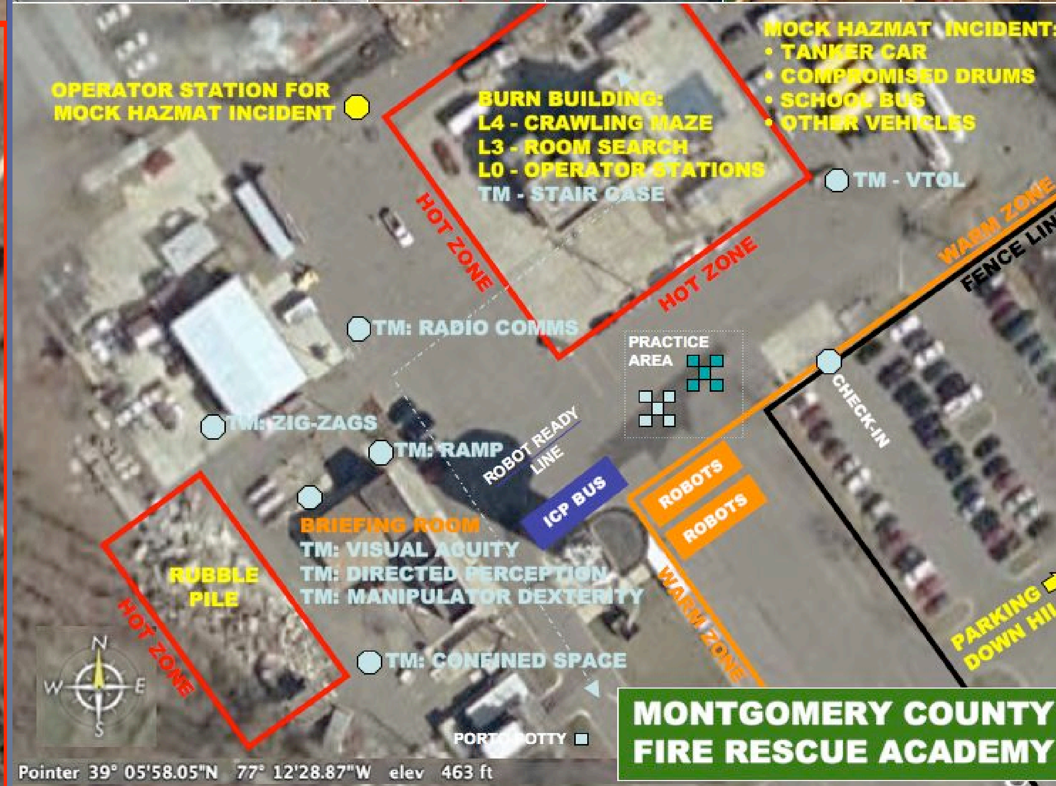
Response Robot Evaluation Exercise

MD-TF1 Training Academy
Rockville, MD
August 19-21, 2006
(with a standards meeting August 21, 2006)

www.isd.mel.nist.gov/us&r_robot_standards usar.robots@nist.gov

Maryland





NV-TF1 August 2005

TX-TF1 April 2006

MD-TF1 August 2006

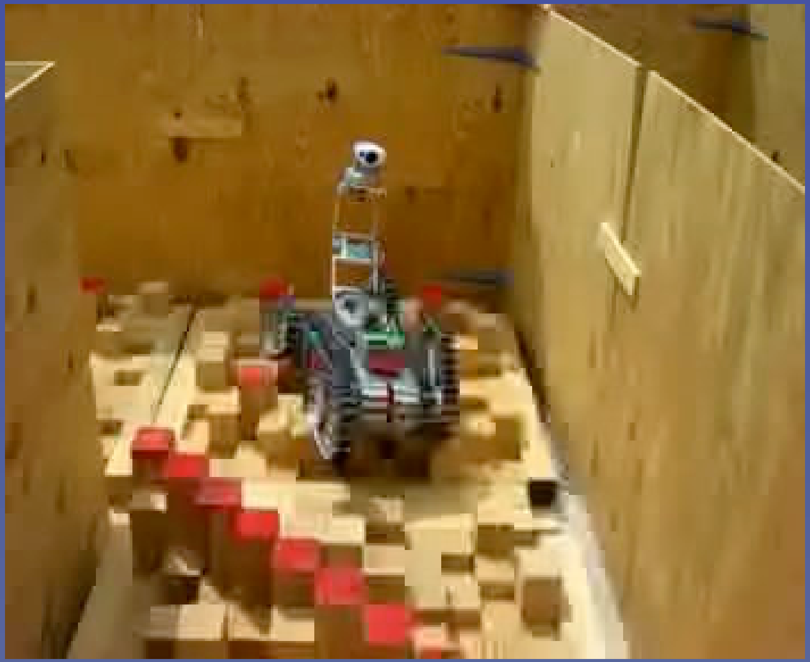
Disaster City

Marsupial Deployment of Omnitech Toughbot by Talon

Foster-Miller Talon Finding Simulated Victim

Who Says Standards are Boring?

WVHTC Bombot



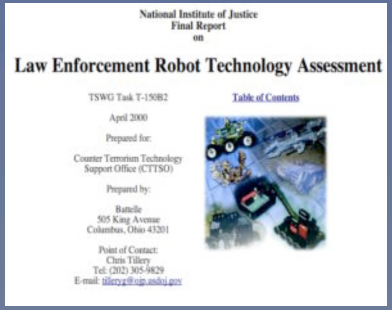
Toin University Hibiscus

Automatika Dragon Runner

ARA LRV

Performance Metrics For Bomb Disposal Robots

- Objective
  - ✳ To develop performance metrics and standard interfaces for explosive ordnance disposal (EOD) robot systems.
- Customers
  - ✳ Support the law enforcement and bomb disposal communities directly, funding agencies (such as DOJ) indirectly
- Leverage
  - ✳ Benefit from test methods developed for US&R robots
  - ✳ Expand upon existing foundational work and captured requirements by NIJ, TSWG, FBI, and others


National Institute of Justice
Final Report
on

Law Enforcement Robot Technology Assessment

TSWG Task T-150B2

April 2000

Prepared for:

Counter Terrorism Technology
Support Office (CTTSO)

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Table of Contents


EOD Robot Training
Camp Lejeune

Ordnance Munitions and
Electronic Maintenance School

Bomb Technician
Robotics Operation Course

Example: Door Opening
(shown with a coordinated control manipulator)

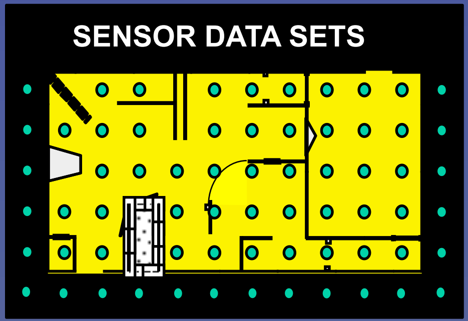
Example: Grasping Dexterity Test Method

(shown with a coordinated control manipulator)

Updating Requirements, Testing the Tests: MetroTech Meeting at NIST

Spectrum Of Test Environments

Test Methods/Competitions | NIST Nike | Responder Sites



VIRTUAL — TEST METHODS — QUALIFYING ARENAS — INDOOR — OUTDOOR, REALITY

Reproducible for Dissemination | Location-specific

Summary

Robotics and associated technologies provide a diverse and evolving set of capabilities for emergency response.

To get these advanced tools into the hands of responders, we are:

- Measuring performance of robots in reproducible, repeatable ways that can correlate to use in the field
- Developing concepts of operation and match the right characteristics to different deployment needs
- Moving toward statistically significant repetitions to capture performance and reliability
- Standardizing performance test methods through ASTM International

Issues Abound....

... beyond those already noted, here are a couple more:

- Interdependencies between components make evaluations difficult
  - e.g. communications and sensors
- Human in the loop really complicates performance measurement
  - taking different demographics into account can help
- Tests require statistically significant number of "samples" or runs

Acknowledgments

This work would not be possible without the contributions of:

- The FEMA USAR Task Force members, representing 23 Task Forces, who ably advise us throughout the process
- The Metrotech and Michigan bomb squads, the National Bomb Squad Commander's Advisory Board, the Hazardous Devices School instructors, TSWG, and others who have defined the requirements for bomb disposal robots
- All the manufacturers and researchers who have voluntarily participated in the exercises and subjected their robots to testing
- The Department of Homeland Security, Science and Technology Directorate, Standards Office
- The National Institute of Justice Office of Science and Technology
- The Standards Working Groups and Support Team (at NIST and elsewhere) including, but not limited to: Adam Jacoff, Brian Antonishek, Stephen Balakirsky, Tony Downs, John Evans, Hui-Min Huang, Galen Koepke, Alan Lytle, Philip Mattson, Bill McBride, Mark Micire, Kate Remley, Debra Russell, Jeanenne Salvermoser, Salvatore Schipani, Craig Schlenoff, Jean Scholtz, Chris Scrapper, Ann Virts, and Brian Weiss

Thank You!

For more information about

Performance Standards
for
USAR Robots:

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